Visual suppression of monocularly presented symbology against a fused background in a simulation and training environment

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ABSTRACT

When wearing a monocular head-mounted display (HMD), one eye views the HMD symbology while both eyes view an out-the-window scene. This may create interocular differences in image characteristics that could disrupt binocular vision by provoking visual suppression, thus reducing visibility of the background scene, monocular symbology, or both. However, binocular fusion of the background scene may mitigate against the occurrence of visual suppression, a hypothesis that was investigated in the present study. Observers simultaneously viewed a static background scene and HMD symbology while performing a target recognition task under several viewing conditions. In a simulated HMD condition observers binocularly viewed a background scene with monocular symbology superimposed. In another condition, viewing was dichoptic (i.e. completely different images were presented to the left and right eyes). Additionally, one control condition was implemented for comparison. The results indicate that for continuously presented targets binocular rivalry did not have significant effects on target visibility. However, for briefly presented targets, binocular rivalry was shown to increase thresholds for target recognition time in HMD and dichoptic viewing conditions relative to the control. Impairment was less in the HMD condition. Thus, binocular fusion of a background scene can partially mitigate against the occurrence of visual suppression. However, some suppression still exists which occurs between monocular pathways. Implications for the integration of monocular HMDs into Air Force training environments will be discussed.

Keywords: binocular rivalry, HMDs, visual suppression

1. INTRODUCTION

Over the past several decades, one important technological advance has been the creation of wearable head-mounted displays (HMDs) for military and commercial applications[1,2,3]. An HMD presents pictorial or symbolic information to either one eye (i.e., monocular HMD) or both eyes (i.e., binocular or biocular HMD) by way of one or two miniature visual displays mounted on the head. HMDs can offer advantages over traditional displays, such as increased situational awareness and ease of mobility[3].

Despite the potential advantages of HMDs, there can be problems with their use. For example, Wenzel, Castillo and Baker[4] found that aircraft maintenance workers reported problems such as eye strain, headache, nausea, and dizziness when a HMD was used for training purposes. Furthermore, Kooi[5] reported significantly greater eyestrain with the use of HMDs relative to that found with a computer monitor. Morphew, Shively, & Casey[6] found that self-reported nausea, disorientation, and oculomotor strain were greater with an HMD compared to a standard computer monitor when an Unmanned Aerial Vehicle control task was performed. And Hakkinen[7] reported similar problems when a monocular HMD was used when a text-editing task was performed. Finally, simulator sickness can occur when HMDs are worn, which can be caused by a number of factors[8,9,10]. Thus, it is not surprising that Keller and Colucci[11] concluded that HMDs have often disappointed real world users.

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14. ABSTRACT

When wearing a monocular head-mounted display (HMD), one eye views the HMD symbology while both eyes view an out-the-window scene. This may create interocular differences in image characteristics that could disrupt binocular vision by provoking visual suppression, thus reducing visibility of the background scene, monocular symbology, or both. However, binocular fusion of the background scene may mitigate against the occurrence of visual suppression, a hypothesis that was investigated in the present study. Observers simultaneously viewed a static background scene and HMD symbology while performing a target recognition task under several viewing conditions. In a simulated HMD condition observers binocularly viewed a background scene with monocular symbology superimposed. In another condition, viewing was dichoptic (i.e. completely different images were presented to the left and right eyes). Additionally, one control condition was implemented for comparison. The results indicate that for continuously presented targets binocular rivalry did not have significant effects on target visibility. However, for briefly presented targets, binocular rivalry was shown to increase thresholds for target recognition time in HMD and dichoptic viewing conditions relative to the control. Impairment was less in the HMD condition. Thus, binocular fusion of a background scene can partially mitigate against the occurrence of visual suppression. However, some suppression still exists which occurs between monocular pathways. Implications for the integration of monocular HMDs into Air Force training environments are discussed.

15. SUBJECT TERMS

Monocular head-mounted displays; HMD; Image characteristics; Binocular fusion; Visual suppression; Target recognition; Binocular rivalry;

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These and other problems arise because HMDs present an unnatural viewing situation, a topic which has been discussed by Patterson et al[2]. In particular, HMDs may create a situation in which the two eyes receive very different stimulation. For example, in the case of a semi-transparent monocular HMD, images from the HMD symbology are presented to one eye while that eye plus the other eye view a real-world scene. In the eye that receives the symbology, those images would overlap the images from the real-world scene and conflict with the images in the other eye. In the case of a binocular HMD, slightly different imagery may be presented to the two eyes if there exists significant optical misalignment or image distortion between the two eyes' views.

When the two eyes receive very different stimulation, a condition exists for creating a phenomenon known as binocular rivalry. Binocular rivalry refers to a state of competition between the eyes, such that one eye inhibits the visual processing of the other eye. The visibility of the images in the two eyes fluctuates, with one eye's view becoming visible while the other eye's view is suppressed, which reverses over time. Importantly, during binocular rivalry, portions of stimulation in only one eye gain access to higher visual processing stages at any one time[12]. According to Blake[13], the perceptual confusion known as rivalry arises because the two eyes signal to the brain that two different objects exist at same time and location. It is important to note that the inhibition or suppression that binocular rivalry engenders acts upon a given area of the retina, not upon the stimulus per se[14]. As pointed out by Patterson et al.[2], binocular rivalry is important to study because it represents a visual process by which information or signals may be missed while using an HMD.

The suppression that defines binocular rivalry requires that stimuli be exposed for at least 200 msec or longer[15]. With sufficiently long exposures, binocular rivalry is provoked by interocular differences in color, contrast polarity, form, size, and motion velocity. It occurs over a wide range of light levels and virtually anywhere in the binocular visual field[13]. With small stimuli, rivalry can appear unitary and suppress from awareness an entire stimulus, whereas with large stimuli the suppression can appear piecemeal and fragmented[16]. This indicates that rivalry affects local retinal regions or zones of suppression[17].

In the fovea, the zone of suppression may be on the order of 10-15 arcmin[17], which increases with eccentricity[18], with the spatial scale (i.e., inversely with spatial frequency) of the stimulus[19,20], and with decreasing light level[21]. Such zones of suppression within an eye may show synchronized alternations if the stimuli in the visual field possess a common configuration or a common color[22,23], which suggests the existence of a cooperative network underlying the binocular rivalry process[13].

The loss of visibility during rivalry suppression appears to be a general loss of sensitivity in so far as different types of stimuli may be rendered invisible, such as brief flashes of light or alphabetic symbols.[24,25] Also, reaction time to a briefly presented probe stimulus may be lengthened during rivalry suppression.[26,27] During suppression, a sensitivity loss in detecting a probe can be on the order of about 0.5 log units.[25,28] This loss in sensitivity is independent of contrast and luminance level.[28] As pointed out by Blake[13], such a sensitivity loss can span a range of functioning from perfect performance down to chance level, which shifts a stimulus from being reliably detectable to being reliably undetectable. It is known that the magnitude of suppression, in terms of the 0.5 log unit loss of sensitivity in luminance, remains at a relatively constant rate during the course of suppression[25,29]. Rivalry between moving stimuli may exhibit a greater depth of suppression[29]. In general, rivalry suppression can impair a number of visual functions: suppression can impair pupillary constriction[30], as well as the ability of observers to visually guide and direct attention to targets in the visual field[31].

There are a number of factors that affect the strength of a stimulus during the rivalry process. Factors that increase stimulus strength include: contour density[32], luminance level[33], contrast level[34], middle spatial frequencies[34,35], size[19] , and velocity[36,37]. In general, a stronger stimulus shows greater predominance during rivalry, where predominance is defined as the total proportion of time a stimulus is visible[13]. Interestingly, it is known that stimulus strength determines the duration for which a given stimulus is suppressed, not the duration for which it suppresses another stimulus; that is, strength plays little role in determining how long a given stimulus is dominant[32,33,38].

The research described above involves the use of dichoptically (i.e. completely different images presented to the left and right eyes) viewed stimuli only. A factor that may affect binocular rivalry is binocular fusion (i.e., sensory blending of the two eyes views). In discussing this idea, recall that with a semi-transparent monocular HMD, the background scene would be viewed by both eyes while one eye views the HMD symbology. In this case, binocular fusion of the background may mitigate against the binocular rivalry that could occur between the imagery in the eye that sees the HMD and the background scene viewed by the other eye[2]. On this point, Blake and Boothroyd[39] showed that when one eye views a set of vertical contours while the other eye simultaneously views a set of vertical contours (which should evoke binocular fusion) together with a set of horizontal contours (which should provoke binocular rivalry), the result is binocular fusion, not rivalry. Liu et al[40] also found that the presence of a fused aperture surrounding a set of test stimuli minimized the occurrence of rivalry. Thus, it is possible that rivalry would not be a significant problem when monocular semi-transparent HMDs are worn if the background scene viewed by both eyes is easily fusible.

However, as noted by Howard[12], it has been suggested that rivalry between different colors occurs within a different visual processing stream than contour rivalry[41]. The chromatic pathways appear to be more affected by rivalry suppression than the achromatic pathway[42]. Moreover, Julesz & Miller[43] showed that binocular rivalry and binocular fusion may occur simultaneously within different spatial frequency bands. Thus, it is possible that binocular fusion of the background would not mitigate against the binocular rivalry that could occur when a monocular semi-transparent HMD is worn because either the rivalry would occur in the chromatic pathways while fusion occurred in the achromatic pathway, or vice versa, or the rivalry would occur in a different frequency band than the fusion.

The purpose of the present study was to investigate whether binocular fusion mitigated against the occurrence of binocular rivalry when a monocular semi-transparent HMD was worn. In this study, observers simultaneously viewed a static background scene and HMD symbology while performing a target recognition task under four viewing conditions. In the HMD condition, one target and the background scene was fused by both eyes, while the other target and HMD symbology were seen by the right eye only. This condition simulated wearing a monocular semi-transparent HMD while viewing a real-world background scene. In the dichoptic condition, one target and the background scene were viewed by the left eye only, while the other target and the HMD symbology were seen by the right eye only. This condition was expected to produce the most rivalry suppression and thus it served to set a lower bound on performance. In the monocular condition, one target and a bright unstructured background were viewed by the left eye only, while the other target, the HMD symbology, and the background scene were viewed by the right eye only. This condition examined whether the background scene and HMD symbology interfered with one another when viewed by the same eye. Finally, in the control condition, the targets, the background scene, and the symbology were fused by both eyes. This condition was expected to produce minimal rivalry suppression and thus it served to set an upper bound on performance. If binocular fusion mitigates against the occurrence of binocular rivalry when monocular semi-transparent HMDs are worn, then recognition performance should be higher under the HMD condition than under the dichoptic condition.

2. EXPERIMENT 1

2.1. Methods

2.1.1. Observers

Nine observers with normal or corrected-to-normal vision participated in this experiment.

2.1.2. Apparatus and Stimuli

Two visual displays were used: a VDC Sim 1600 LCoS projector and an Eizo Flexscan 985 Ex LCD flat panel display. The LCoS display rear-projected an image onto a small DA-Lite DASS screen, which was viewed through a beam splitter to allow the symbology and OTW display (see Figure 1a) to be optically combined. The symbology was similar to that used with the Joint Helmet Mounted Cueing System (JHMCS, see Figure 1b). The combination of the LCoS display and beam splitter was referred to as the simulated-HMD display (HMD). The LCD flat panel display projected a realistic static scene of Nellis AFB near Las Vegas, NV, and was referred to as the out-the-window (OTW) display. To equalize the luminance presented to the two eyes, the OTW display was also viewed through a beam splitter. The target stimuli were two white block letter E's, with contrast approximately 0.05. The E's were positioned on either side of a fixation cross. The E's randomly changed direction so that they could be facing rightward or leftward. The change in direction occurred in a time interval of 5 to 15 seconds. One E appeared on the OTW display and one on the HMD display. Each target letter E was 0.7 degree in size, similar to the smallest symbol size that might appear on a head-up display (HUD).

A separate set of stimuli was used for a rivalry dominance task. For this task a vertical grille pattern was displayed on the OTW display and a horizontal grille pattern was displayed on the HMD display. The grille patterns were matched for size, luminance, contrast, and spatial frequency. When viewed through the beam splitter the grille patterns completely overlapped.

The viewing distance to each display was 36 inches, matching the viewing distance in the Air Force flight simulator display system, the Mobile Modular Display for Advanced Research and Training (M2DART)[44]. A chin rest stabilized observer head position. A PC was used to present the imagery and record responses.

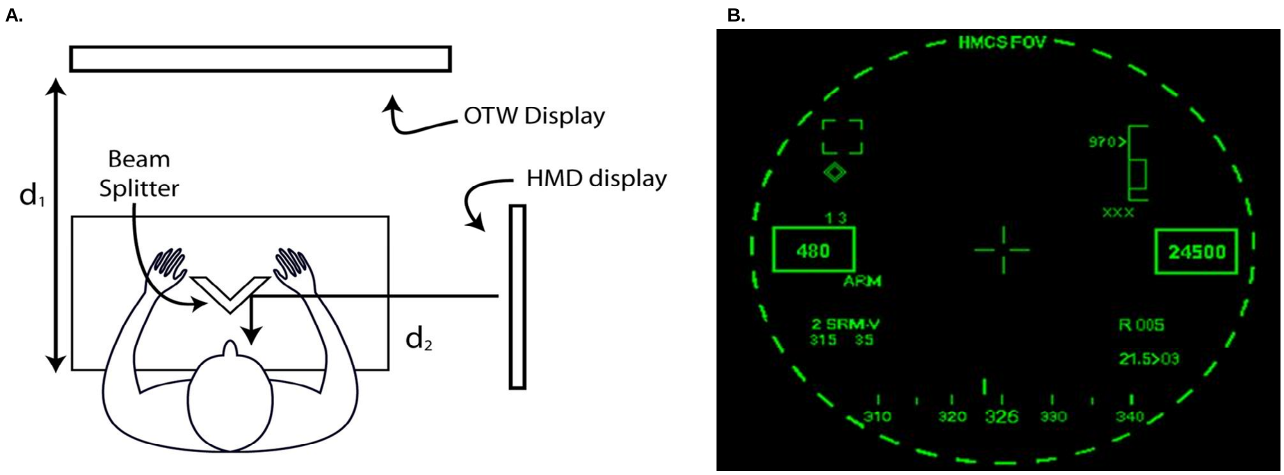

Figure 1. A. Position of OTW and HMD displays, d_1 and d_2 were both 36 inches. B. Symbology viewed by observers.

2.1.3. Procedure

Observers were first tested for acuity, phoria, depth perception, sighting dominance, and rivalry dominance. An Optec vision tester was used to assess acuity, phoria, and depth perception. For sighting dominance observers were asked to look through a dioptometer at a distant object and instructed to adjust the dioptometer for good focus. The eye the observer used to look through the dioptometer was recorded. A task similar to the "hole task" described by Coren and Caplan[45] was also used to assess sighting dominance. Rivalry dominance was assessed using the grille patterns described above. Observers were instructed to view the overlapping grille patterns through the beam splitter and indicate using the mouse whether they saw a vertical or horizontal grille pattern. The amount of time each was visible during a 5 minute session was recorded.

Four viewing conditions were established. In the HMD condition, the observers viewed the OTW scene with both eyes and the HMD symbology with their right eye. In the dichoptic condition, the observers viewed the OTW scene with their left eye and the HMD symbology with their right eye. In the control condition, the observers viewed both the OTW scene and the HMD symbology with both eyes. In a fourth condition (monocular), observers viewed both the Nellis scene and the symbology on the HMD display with the right eye. The OTW displayed only a homogenous gray field that was equal in luminance to the HMD. This served as a second dichoptic condition.

The observers' first task was to detect the change in orientation of the E's and indicate, using a mouse, which E (left or right) had changed orientation. Observers performed this task under the four different viewing conditions for a total of 120 trials. Each change in target letter orientation constituted a trial. Changes in target letter orientation occurred randomly during an interval from 5 to 15 seconds. A second set of 120 trials was also performed in which the position of the HMD and OTW E's were reversed. Reaction time and percentage correct were recorded.

In an additional experimental condition, and for each viewing condition, observers indicated using a mouse whether or not each E was visible. The percentage of time each E was visible was recorded. For this additional condition, the stimuli were identical to those described above. The only difference was the response measure – a subjective measure of the visibility of the targets.

2.2. Results

The percentage of correctly identified changes in target orientation across the 30 trials collected under each condition was computed to provide an estimate of response accuracy for each observer under each condition. Figure 2a shows the percentage correct averaged across all observers and across normal and reversed position of the target. These data were analyzed by an analysis of variance, which showed that there was a significant effect of the position (normal or reversed) of the target letter E's [$F(1, 7) = 8.7$, $p < 0.05$]. However, the effects of viewing condition [$F(2.04, 14.3) = 2.9$, $p = 0.09$] and display [$F(1, 7) = 0.7$, $p = 0.43$] were not significant. There was a significant position x viewing condition interaction [$F(1.6, 11.4) = 5.6$, $p < 0.05$].

For the reaction time scores, the reaction times associated with the 30 trials collected under each condition were averaged together for each observer to provide an estimate of response latency for each observer under each condition. Figure 2b shows the reaction times for each condition averaged over all observers and across the normal and reversed condition of the target letter E positions. These data were analyzed by an analysis of variance, which showed that there were no significant effects.

For the subjective visibility task, observers typically indicated that targets were less visible in the dichoptic and monocular conditions. There was little difference between the control and HMD conditions. These results are shown in Figure 3. An analysis of variance indicates that effect of viewing condition was significant [$F(1.5, 10.7) = 4.4$, $p < 0.05$]. Figure 3 shows the average percentage of time (during each 5 minute session) targets were suppressed for each condition.

An additional correlation analysis indicated that right eye sighting dominant observers tended to have higher accuracy in several of the conditions: Reversed/HMD/HMD [$r = -0.92$, $p < 0.01$], Reversed/Monocular/HMD [$r = -0.97$, $p < 0.01$], and Normal/Control/HMD [$r = -0.74$, $p < 0.05$]. These observers also tended to have shorter reaction times for the Normal/Monocular/OTW condition [$r = -0.848$, $p < 0.01$].

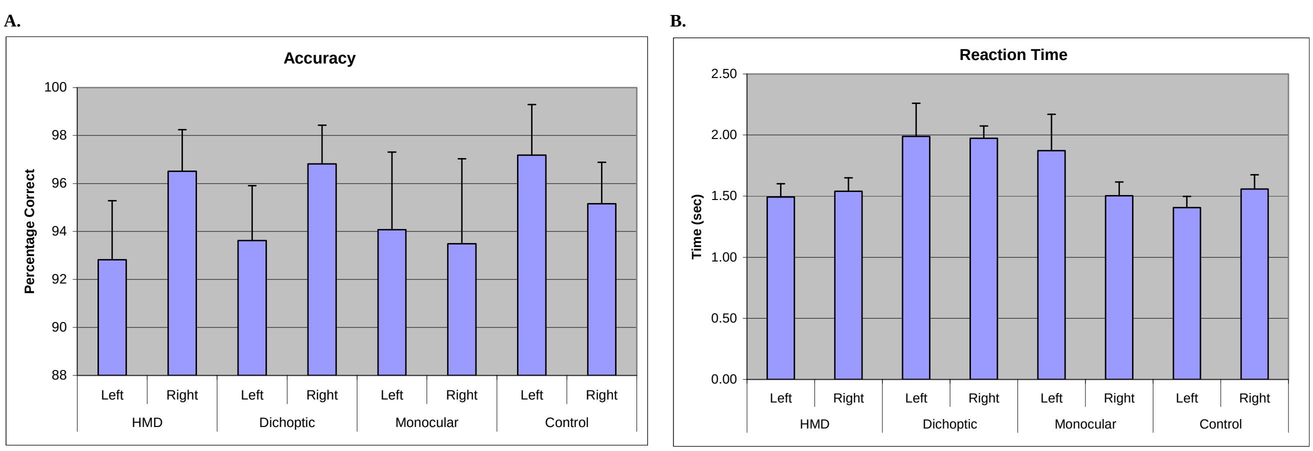

Figure 2. A: Accuracy in identifying change in orientation of the targets for each viewing condition. B: Reaction times for recognizing changes in orientation of the targets for each viewing condition.

2.3. Discussion

The results of Experiment 1 generally show little difference in performance between the control and HMD viewing conditions. However, there is some indication that the Dichoptic and Monocular viewing conditions reduced performance in accurately recognizing change in direction of the target stimuli. Because observers subjectively reported decreased visibility of the targets in the HMD and dichoptic viewing conditions we devised a second experiment which we believed would be more sensitive to brief periods of suppression that could occur as a result of binocular rivalry.

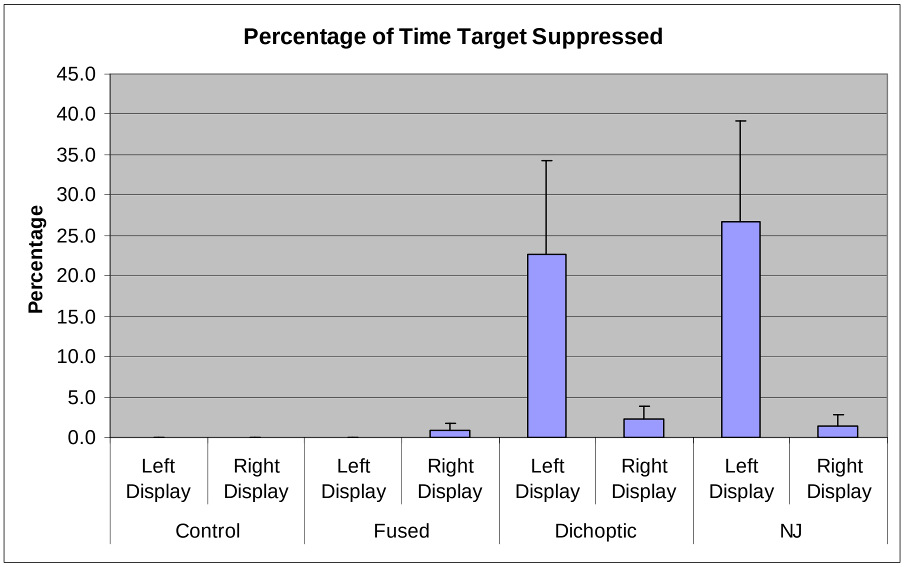

Figure 3. Percent target suppression for each viewing condition.

Experiment 2

2.4. Methods

2.4.1. Observers

Six observers with normal or corrected-to-normal vision participated in this experiment.

2.4.2. Apparatus and stimuli

The apparatus was identical that of Experiment 1. The viewing conditions (HMD, dichoptic, and control) were similar except that the monocular condition was not included. The target stimuli were the same white block letter E's used in Experiment 1, however, instead of being continuously presented, the target E's were briefly presented. The positions in which the target letter E's were presented were the same, to the left and right of the fixation cross.

2.4.3. Procedure

For each viewing condition, observers indicated the orientation of the E (leftward or rightward) using a mouse. The duration of presentation was varied from 2 to 23 video frames (33 to 384 msec). The order of conditions was randomly administered to observers, and the order of E duration was randomly assigned. Percentage correct was recorded for each viewing condition, position of presentation (OTW vs. HMD), and duration. Percentage correct was averaged across left of the cross/right of the cross to factor out differences in visibility against the background for those two positions. In order to estimate threshold duration for recognition of orientation a Weibull function was generated for each viewing condition, position, and duration. Stimulus presentation duration at the 0.63 proportion correct level was taken as threshold.

2.5. Results

Figure 4 shows an example of how thresholds were estimated for one subject in the HMD viewing condition. Proportion correct as presentation duration decreased from 384 msec to 33 msec is indicated with the solid black circles.

The Weibull function fit to the data is indicated with the solid black line. The threshold level (0.63) is indicated by the dashed line. Figure 4a shows data for the stimuli presented on the OTW display, Figure 4b shows data for stimuli presented on the HMD display. As shown by the shift in the intersection of the Weibull fit with threshold level, threshold increased for the HMD relative to the OTW for this observer.

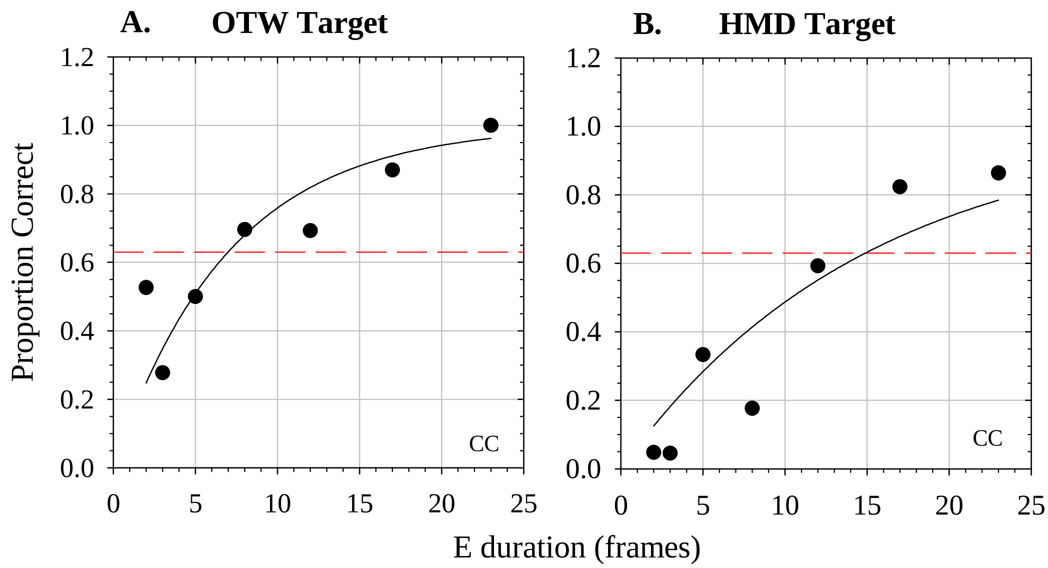

Figure 4. Proportion correct for one observer as presentation duration is decreased for the HMD viewing condition. 1 frame = 1/60 second (16.7 msec).

Figure 5 shows thresholds averaged over observers for the 3 viewing conditions and 2 presentation positions of the stimuli. This figure indicates that thresholds were clearly highest for the OTW presented E in the dichoptic viewing condition, intermediate for the HMD presented E in the HMD condition, and lowest for the two control viewing conditions. A repeated measures ANOVA indicated that the overall effect of viewing condition was not significant [$F(1.1, 4.6) = 5.9$, $p = 0.06$]. However, there was a significant viewing condition x display interaction [$F(1.0, 4.1) = 12.6$, $p < 0.05$].

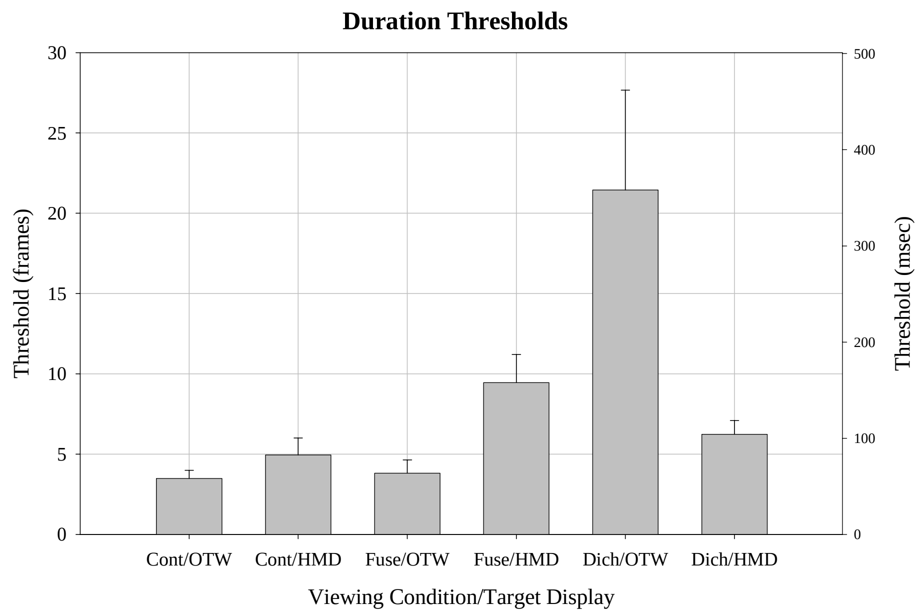

Figure 5. Average thresholds across viewing condition and target display.

2.6. Discussion

The results of Experiment 2 indicate that visibility of OTW presented targets was impaired in the dichoptic viewing condition. Although there was no overall effect of viewing condition, there was a strong interaction between viewing condition and display. This implies that the static Nellis background scenery suppressed the HMD presented targets to some extent in the HMD condition, but that the opposite occurred in the Dichoptic viewing condition – the HMD presented imagery suppressed the Nellis background scene. Subjectively, observers noted that the grey background against which the symbology was presented rivaled strongly with the light-colored Nellis AFB static scene. They noted that the green symbology, however, was always visible against the background, even while the grey background was under suppression.

Unlike the results of experiment 1, the results of Experiment 2 provide some evidence that the monocularly displayed target in the HMD condition suffered from decreased visibility relative to the control condition. This is evidenced by the increased thresholds in that condition.

3. CONCLUSION

The results of this study show that for low contrast, briefly presented targets, monocular presentation is impaired relative to binocular. This impairment is likely due to the effects of binocular rivalry and alternating periods of suppression of the OTW vs. HMD imagery.

Performance for continuously presented targets was less conclusive. There was some evidence that changes in target orientation went unnoticed more frequently by observers in the HMD, monocular, and dichoptic viewing conditions. However, the effect was not consistent across observers and was not significant. The results of the correlation analysis hint that there may be some effect of sighting dominance in determining the visibility of targets undergoing rivalry suppression. However, more observers are needed to test this hypothesis.

Taken together, the results of the two experiments presented here indicate that observers may take a greater amount of time to recognize and act upon low visibility targets presented on a monocular HMD. However, there is no evidence of significant impairment for viewing either the HMD presented monocular imagery or the binocularly viewed OTW scene.

Our results are consistent with those of Blake and Boothroyd[39]. These authors found that binocular fusion mitigates the occurrence of binocular rivalry when the two states of binocular vision are simultaneously elicited when viewing a display. The present results are also consistent with those of Liu et al[40]. These authors reported that the presence of a fused aperture surrounding a set of test stimuli minimized the occurrence of rivalry.

Note that binocular fusion may not mitigate against binocular rivalry when a dynamic background scene is viewed. This is because moving stimuli are more dominant than stationary stimuli during the rivalry process[36,24], and rivalry involving moving stimuli shows a greater depth of suppression[29]. Consistent with this idea, Laramee and Ware[46] found that response times were significantly greater on a table look-up task when the table was presented on a transparent monocular HMD while the observers binocularly viewed dynamic background imagery presented on a television. We are currently investigating this question in our laboratory.

We conclude that binocular fusion of a static background scene can mitigate against the potential binocular rivalry that might occur when a monocular semi-transparent HMD is worn in an Air Force training and simulation environment. Nonetheless, some rivalry suppression appears to be present and future research should be directed toward investigating the type of tasks that may be affected by this residual interference, and further whether this interference differs within a low luminance, close-focus simulation environment versus a high luminance, infinity focus real world environment.

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